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UCRL-PROC-220191

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March 28, 2006

EUSPEN 6th International Conference
Baden, Austria
May 28, 2006 through June 1, 2006

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A comparison of drive mechanisms for precision motion controlled stages

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Abstract

This abstract presents a comparison of two drive mechanisms, a Roh'lix® drive and a polymer nut drive, for precision motion controlled stages. A single-axis long-range stage with a 50 mm traverse combined with a short-range stage with a 16 μm traverse at a operational bandwidth of 2.2 kHz were developed to evaluate the performance of the drives. The polymer nut and Roh'lix® drives showed 4 nm RMS and 7 nm RMS positioning capabilities respectively, with traverses of 5 mm at a maximum velocity of 0.15 $mm{\cdot}s^{-1}$ with the short range stage operating at a 2.2 kHz bandwidth. Further results will be presented in the subsequent sections[1].

Drive mechanism design

Roh'lix® drive

A custom made Roh'lix® nut was donated by Zero-Max that utilizes 3 ball bearings, at each end, and set at a desired lead angle to obtain 0.32 mm per revolution pitch, see Figure 1a. A spring and screw combination was used to ensure that the ball bearings remained in contact with the drive shaft with a constant preload force. Modification to the Roh'lix® nut was made after initial tests indicated a change in pitch of the contact bearings (due to an axial force applied by a combination of sliding resistance of the carriage and friction forces between the

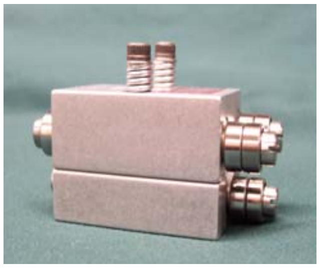
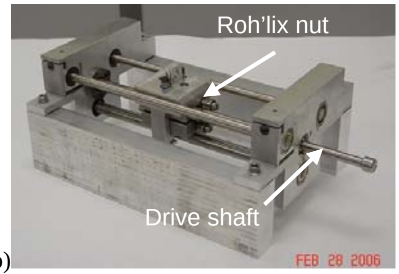
a)  b) 

Figure 1: a) Roh'lix® nut from Zero-Max with angular contact bearings b) Complete Roh'lix® drive mechanism assembly.

ball bearing and the counterface shaft) with each successive traverse. The ball bearings were replaced with angular contact bearings in an attempt to attenuate the pitch changes. Figure 1b shows the completed Roh'lix® drive with a 9.53 mm diameter stainless steel rod utilized as the drive shaft. The Roh'lix® drive mechanism was then placed into a single axis slideway discussed in the subsequent section.

Polymer nut drive

A second alternative drive was designed and build with a custom polymer nut drive consisting of a 3.1 threads·mm^{-1} feedscrew and polymer contacting nut, see Figure 2a. Design of the nut was based on the principle of the Roh'lix® nut, having two halves with 2 pairs of 3 contact pads made of ultra-high molecular weight polyethylene (UHMWPE) spaced 120 degrees apart. Two screw/spring combinations were used to apply a vertical force (to cause a deformation of the polymer onto the threads of the feedscrew) to preload the nut onto the feedscrew. The polymer nut and feedscrew were incorporated in a similar fashion to the Roh'lix® drive, see Figure 2b.

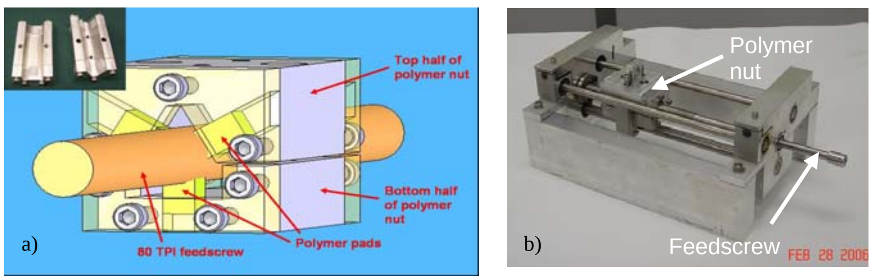


Figure 2: a) Polymer nut, top and bottom halves shown in inset b) Complete feedscrew drive mechanism.

Overview of single axis slideway

To test the individual drive mechanisms, a single axis slideway comprising of a long-range stage with a short-range stage stacked on top, was constructed. The single-axis long-range stage was constructed with the following components to achieve a 50 mm traverse: slideway with UHMWPE bearings [2], Aerotech Inc. DC brushless motor, and Zerodur™ optical flats as a counterface to the UHMWPE bearings. The short-range stage employed a simple single degree-of-freedom (DOF) flexure driven by a PZT to achieve translations of 16 μm at a maximum operational bandwidth of 2.2 kHz. To collect data, a dSPACE controller, model 1103, was utilized in conjunction with a Zygo laser head, model DMI 7712, to measure displacements of the stage. Figure 3 shows the completed single axis slideway test set-up with the feedscrew drive mechanism installed.

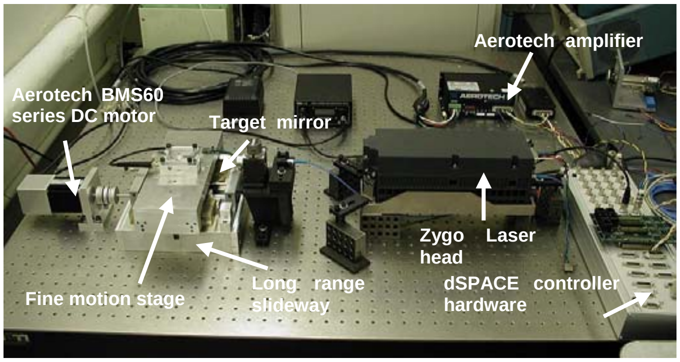


Figure 3: Test set-up of single axis slideway

Results

Table 1 and 2 show the following errors of the Roh'lix® drive and the polymer nut drive in the single axis slideway when subject to a sinusoidal demand corresponding to traverses of 1 and 5 mm, respectively. From this it becomes apparent that the positioning capability of the single axis slideway is directly proportional to the bandwidth of the short range stage and its ability to reduce positioning error.

Table 1: 1 mm traverse results of both the Roh'lix® and feedscrew drive at various bandwidths with a maximum traverse velocity of 25 $\mu m \cdot s^{-1}$.

	Polymer nut drive				Roh'lix® drive	
	Original wobble pin		New wobble pin		New wobble pin	
Bandwidth of piezo stage (Hz)	Peak-to-peak error (nm)	RMS (nm)	Peak-to-peak error (nm)	RMS (nm)	Peak-to-peak error (nm)	RMS (nm)
91	59.3	4.3	5.12	4.1	126.9	11.5
190	25.2	1.8	NA	NA	76.9	6.1
437	13.5	1.0	11.5	1.0	30.6	2.6
1446	8.1	0.8	NA	NA	19.4	1.5
2188	7.8	0.7	5.8	0.7	16.9	1.2

Table 2: 5 mm traverse results of both the Roh'lix® and feedscrew drive at various bandwidths with a maximum traverse velocity of 150 $\mu m \cdot s^{-1}$.

	Polymer nut drive				Roh'lix® drive	
	Original wobble pin		New wobble pin		New wobble pin	
Bandwidth of piezo stage (Hz)	Peak-to-peak error (nm)	RMS (nm)	Peak-to-peak error (nm)	RMS (nm)	Peak-to-peak error (nm)	RMS (nm)
91	601.3	48.4	265.4	17.5	971.8	71.4
190	281.1	24.4	NA	NA	660.8	37.6
437	137.3	12.0	NA	NA	309.5	20.5
1446	67.1	6.1	NA	NA	194.7	10.9
2188	42.1	4	21.5	1.6	111.8	7.1

Comparing translation from encoder position to laser interferometer position, indicated that the Roh'lix® drive and polymer nut drive had pitch variations during traverses of approximately 6 μm and 20 μm, respectively, see Figure 4. It should be noted that the short-range stage was not operational during these tests. Since the motion variations of the polymer nut drive are smooth, this error is readily reduced under closed loop control [3]. The variation during traverses of the polymer nut can be attributed to greater frictional forces transmitted into the slideway. Figure 5 shows the backlash of the individual drives to be approximately 0.4 μm for the Roh'lix® drive and 45 μm for the polymer nut drive. From Figure 5a it became apparent that the Roh'lix® drive mechanism changed pitch from successive motions of the stage making simple feedforward control infeasible.

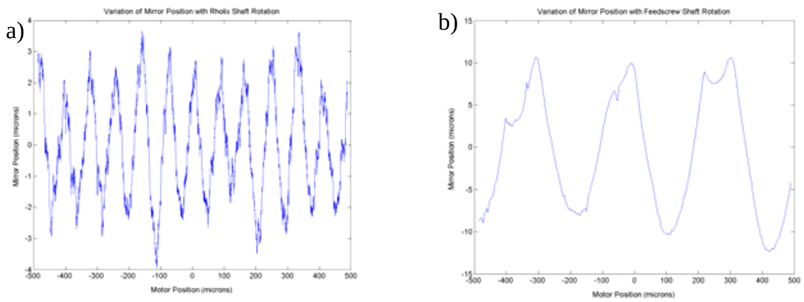


Figure 4: Pitch variations during 1 mm sinusoidal translation a) Roh'lix® drive and b) polymer nut drive.

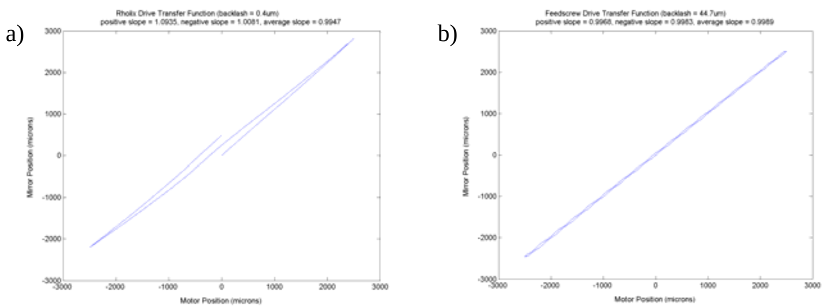


Figure 5: Backlash measurements of the a) Roh'lix® drive and b) polymer nut drive.

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[1] This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48

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[3]Yang H., Buice E., Smith S.T., Hocken R.J., Fagan T, David Otten, David L. Trumper and Seugling R.M., 2005, Design and performance evaluation of a coarse/fine precision motion control system, *Proc. EUSPEN. Annual meeting*, Montpelier, France.